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PROTECTIVE CIRCUIT FOR ELECTRON DISCHARGE DEVICES
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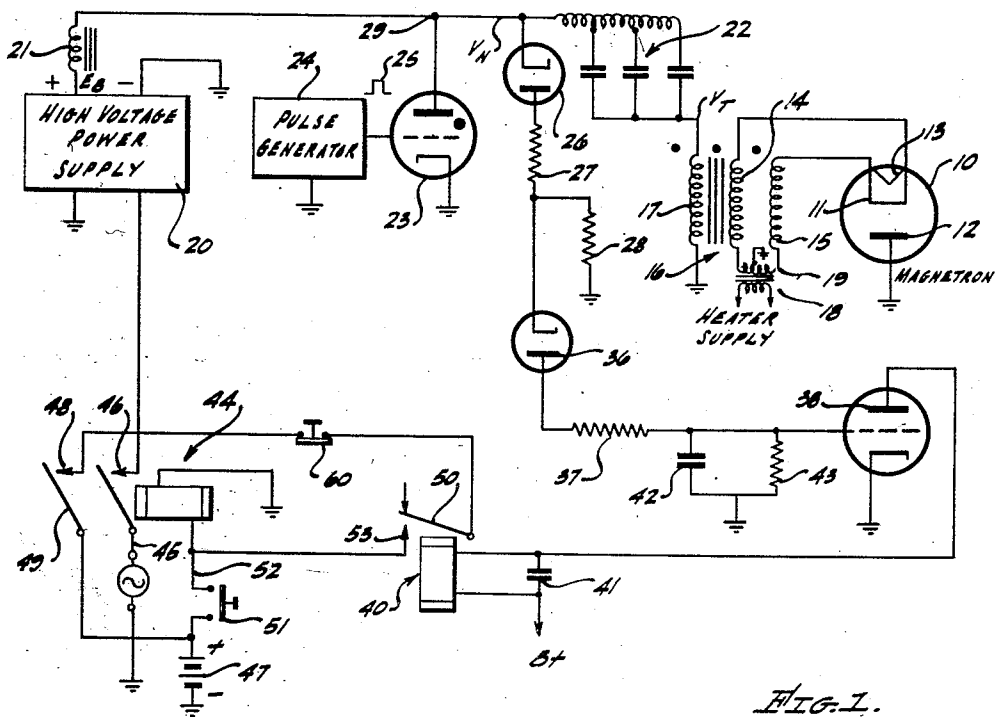


FIG. 1.

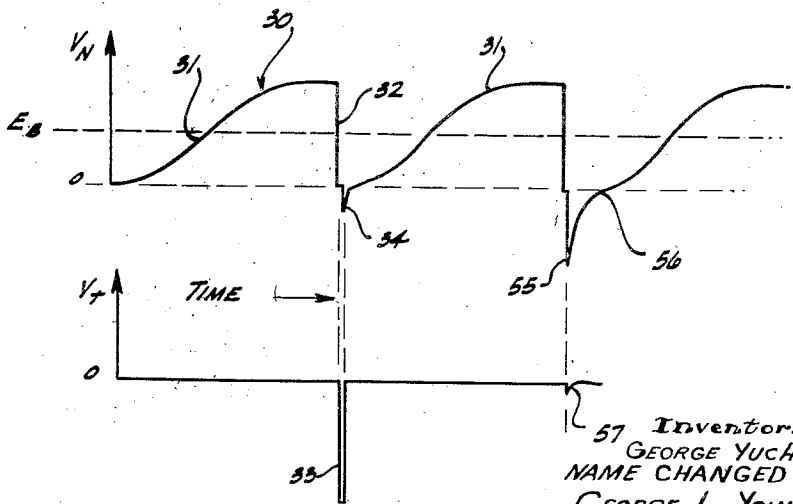


FIG. 2.

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PROTECTIVE CIRCUIT FOR ELECTRON DISCHARGE DEVICES

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This invention relates generally to systems for protecting electron discharge devices, and more particularly relates to a protective circuit for preventing damage to electron tubes and associated equipment which may result from prolonged sparking within such tubes.

The protective circuit of the present invention is particularly adapted for protecting a magnetron of the type utilized in a radar system. It is conventional practice to energize the transmitter magnetron of the radar system periodically by high voltage unidirectional pulses to develop pulsed envelopes of the carrier frequency to be transmitted. Such magnetrons are subject to sparking or internal breakdown which may result from ionization of the residual gases in the magnetron. During such sparking, the impedance presented by the electron discharge path of the magnetron suddenly decreases to a low value. If the sparking or internal breakdown of the magnetron continues for a large number of successive pulses, the magnetron and its associated equipment are damaged.

Occasional sparking of the magnetron will not damage the tube. Consequently, it is desirable to distinguish between occasional sparking of the magnetron and prolonged sparking which would eventually damage the magnetron beyond repair. In order to prevent such damage, the high voltage pulses which are periodically applied across the magnetron should be interrupted in case of sparking that continues for any length of time. In accordance with the present invention, this is accomplished by developing a voltage in response to internal breakdown of the magnetron or other electron discharge device. This voltage is impressed on a time-constant circuit including a capacitor or other charge storage means. The time constant of the circuit is such that a voltage is gradually built up over a period of time, which voltage may be utilized to disconnect the supply from the magnetron pulser. The time constant of the circuit is sufficiently long so that its voltage will not build up to the value required for interrupting the pulse input to the magnetron unless the breakdown of the magnetron prevails for a predetermined length of time.

It is accordingly an object of the present invention to provide a protective circuit for electron discharge devices.

Another object of the present invention is to provide a circuit for preventing damage to pulsed magnetrons which may be caused by prolonged sparking.

A further object of the present invention is to provide a protective circuit for a pulsed magnetron which will deenergize the magnetron in response to prolonged sparking thereof, and which is unaffected by occasional sparking which does not exceed a predetermined length of time.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the

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accompanying drawing in which an embodiment of the invention is illustrated by way of example, and the scope of the invention is pointed out in the appended claims. In the drawing,

Fig. 1 is a circuit diagram, partly in block form, of a pulsed magnetron provided with a protective circuit in accordance with the present invention; and

Fig. 2 is a graph illustrating voltages developed at various points of the circuit of Fig. 1 and plotted as a function of time.

Referring now to the drawing and particularly to Fig. 1, there is illustrated schematically a magnetron 10 including a cathode 11 and an anode 12 which may be grounded, as shown. Cathode 11 preferably is indirectly heated by a filament 13 which may be energized from a suitable source of heater supply, as shown, through a transformer 13 having the midpoint of its secondary winding 19 grounded. Secondary winding 19 is connected to heater filament 13 through a pair of windings 14 and 15 which form secondary windings of a transformer 16 having a primary winding 17. Windings 14 and 15 preferably are bifilar windings.

In accordance with conventional practice, the magnetron 10 is periodically energized by impressing a high voltage on primary winding 17 to develop a still higher negative voltage across secondary windings 14 and 15. This may, for example, be done by utilizing a line-type modulator employing a unidirectional switch, such as a thyatron, which is periodically rendered conducting by trigger pulses impressed on the grid thereof. Such a conventional circuit for periodically energizing the magnetron 10 will now be described for providing a better understanding of the protective circuit of the invention.

A positive voltage is developed by a power supply 20 having its negative terminal grounded while its positive output terminal is connected through an inductor 21 to a pulse-forming network 22 which may, for example, be a transmission line or a simulated transmission line, as shown. Pulse-forming network 22, as illustrated, consists of a two-terminal network including an inductor having intermediate and end taps connected to three capacitors connected in parallel. Pulse-forming network 22 is serially connected with choke 21 between the positive output terminal of high voltage supply 20 and one terminal of primary winding 17; the other terminal of primary winding 17 may be grounded as shown.

A unidirectional switch which may, for example, be a thyatron 23, as shown, such as a hydrogen thyatron, is connected between the junction point 29 of choke 21 and pulse-forming network 22, and ground. The cathode of thyatron 23 may be directly grounded, as shown, and a suitable pulse generator 24 connected between its control grid and ground. Thyatron 23 is arranged to be normally nonconducting and is periodically rendered conducting by positive pulses depicted at 25 which are developed by pulse generator 24 and impressed on the control grid of the thyatron. A clipper rectifier 26 has its cathode connected to the junction point 29, while its anode is grounded through two serially-connected resistors 27 and 28.

The circuit described thus far is conventional and its operation is well known. The high positive voltage developed by power supply 20 is impressed through choke 21 on pulse-forming network 22. The voltage at the junction point 29 may be designated V_N and is plotted as a function of time in Fig. 2, to which reference is now made. Thus, curve 30 of Fig. 2 illustrates the voltage V_N and curve portion 31 indicates the voltage build-up across the capacitors of pulse-forming network 22 during the interval when thyatron 23 is nonconducting. E_B indicates the positive output voltage of power supply 20

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as shown in Fig. 1, and it will be noted from curve 30 that due to the pulse-forming network 22, the voltage V_N rises to a value approximately twice that of E_B .

Eventually, upon the occurrence of a trigger pulse 25, thyatron 23 will be rendered conducting and its impedance drops to an extremely low value of the order of one ohm. Consequently, the charge previously built up across the capacitors of pulse-forming network 22, is suddenly and rapidly discharged as shown by curve portion 32 in Fig. 2. As soon as thyatron 23 begins to conduct, the voltage V_N drops to almost zero. The discharge path may be traced from pulse-forming network 22 through thyatron 23, ground, primary winding 17, and back to pulse-forming network 22. During the time interval when thyatron 23 does not conduct, the voltage V_T , that is, the voltage across the primary winding 17 of transformer 16, which is grounded, is zero. Consequently, when thyatron 23 begins to conduct, the voltage V_T across primary winding 17 goes in a negative direction, as indicated by curve portion 33 of Fig. 2. Curve portion 33 illustrates the voltage V_T as a function of time, which is the voltage across primary winding 17 as shown in Fig. 1. As soon as thyatron 23 begins to conduct, high voltage power supply 20 is effectively disconnected from pulse-forming network 22 due to the isolation provided by choke 21.

If transformer 16 provided a perfect impedance match to the load presented by magnetron 10, voltage V_N would never go to a negative value. However, as shown in Fig. 2, the voltage V_N may normally have a small negative excursion shown by curve portion 34. This negative voltage which momentarily exists at the cathode of clipper rectifier 26, renders the rectifier conducting, thus developing a small negative voltage at the junction point of resistors 27, 28.

Let it now be assumed that magnetron 10 suddenly sparks due to internal breakdown. As previously pointed out, if the sparking continues for any length of time, the magnetron 10 and its associated equipment, including transformer 16, pulse-forming network 22, thyatron 23, and clipper rectifier 26, may be damaged. In accordance with the present invention, this is prevented by a protective circuit including a rectifier 36 having its cathode connected to the junction of resistors 27, 28. The anode of rectifier 36 is connected through a current limiting resistor 37 to the control grid of an amplifier 38, which may be a triode, as shown, having its cathode grounded. The anode of triode 38 is connected through the winding of a relay 40 to a suitable anode voltage supply indicated at B+. In case the anode voltage supply B+ is an alternating-current voltage, a capacitor 41 may be connected across the winding of relay 40 to prevent chattering of the relay. Relay 40 preferably is a sensitive relay having a contact arm which will handle small currents only.

A capacitor 42 and a resistor 43 are connected in parallel between the control grid of triode 38 and ground. As will be more fully explained hereafter, the resistance of resistor 37 is small compared to that of resistor 43, so that the time constant of the RC circuit 37—42 is small compared to that of the RC circuit 42—43.

Relay 40 controls the energizing voltage for high voltage supply 20 by means of a second relay 44, which preferably is a heavy duty relay. A suitable source of alternating current is connected between ground and lead 45, as indicated, and lead 45 may be connected through relay contact 46 to power supply 20. A suitable source of direct-current voltage, such as battery 47, has its negative terminal grounded while its positive terminal may be connected through a contact arm 49 to a contact 48 of relay 44, which in turn is connected to the contact arm 50 of relay 40. The positive terminal of battery 47 may be connected through a manual start button 51 and lead 52 to the winding of relay 44; the other terminal of the relay winding is grounded. Lead 52 in turn is connected to contact 53 of relay 40.

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The high voltage supply 20 is energized in the following manner. Triode 38 is normally conducting and hence the winding of relay 40 is normally energized. Accordingly, contact arm 50 is attracted by its relay 40 and makes contact with contact 53. As soon as start button 51 is momentarily depressed, relay 44 is energized and its two movable contact arms are attracted. Consequently, the alternating current source is connected by lead 45 and contact 46 to high voltage power supply 20. When start button 51 is released, relay 44 remains energized through its own holding circuit which may be traced from the positive terminal of battery 47 through contact 48, movable contact arm 50 of relay 40, contact 53 and through the winding of relay 44 back to ground. Hence, as long as triode 38 conducts, high voltage power supply 20 remains energized, thereby to energize magnetron 10 periodically.

Let it now be assumed that magnetron 10 sparks. Consequently, the impedance between its cathode 11 and anode 12 is reduced to approximately zero resistance, and the voltage across pulse-forming network 22 discharges into a substantially short-circuited load. Accordingly, the voltage V_N drops to a greater negative value, as shown by curve portion 55 in Fig. 2. The voltage V_N again builds up to a positive value as shown by curve portion 56 of Fig. 2. The large negative voltage shown by curve portion 55 will render clipper rectifier 26 conducting. The resulting voltage drop across resistors 27, 28 will drive the voltage of the junction point of resistors 27, 28 to a negative value. Preferably, the resistance of resistor 28 is small to reduce its power dissipation so that the cathode of rectifier 36 may be operated at a low potential with respect to the heater of the cathode. This negative voltage which is developed at the junction of resistors 27, 28 will in turn render rectifier 36 conducting, and capacitor 42 is charged to a negative potential through resistor 37. However, the voltage across capacitor 42 which is built up in this manner is insufficient to bias triode 38 to cut-off. As shown by curve portion 57 of Fig. 2, the voltage V_T is relatively small; this is due to the fact that the low impedance of the sparking magnetron 10 is reflected through secondary windings 14, 15 into primary winding 17, which is now substantially short-circuited.

As explained before, the resistance of resistor 43 is large compared to that of resistor 37. Furthermore, the time constant of the RC network 42, 43 should be large compared to the time interval between successive trigger pulses 25. Accordingly, the charge across capacitor 42 will leak off only to a small extent through resistor 43 between successive trigger pulses 25.

Consequently, if magnetron 10 sparks only occasionally, the voltage built up across capacitor 42 will eventually be dissipated again, so that triode 38 is not cut-off. On the other hand, if sparking continues for a predetermined length of time determined by the time constants of RC networks 37—42 and 42—43, the charge across capacitor 42 will eventually build up to a value sufficient to cut off triode 38.

Accordingly, the winding of relay 40 is deenergized to break the holding circuit for relay 44 which includes contact arm 50 of relay 40. Hence, the winding of relay 44 is also deenergized and the alternating-current source is disconnected from high voltage power supply 20. Therefore, further damage to magnetron 10, transformer 16, pulse-forming network 22, thyatron 23, clipper rectifier 26 and other associated equipment is effectively prevented. It is to be noted that once relay 44 is deenergized, it cannot be energized again until start button 51 is depressed. Relay 44 may be deenergized and the alternating current source for high voltage power supply 20 may be disconnected by manually depressing stop button 60 disposed in the holding circuit of relay 44.

The actual circuit constants of the protective circuit of the invention may best be determined by experiment. To

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this end magnetron 10 may be replaced by a resistor of low resistance and the circuit constants adjusted until relay 40 becomes deenergized after a predetermined length of time.

What is claimed is:

1. A protective circuit for a magnetron having a discharge path between a cathode and an anode thereof subject to internal breakdown due to sparking, whereby the impedance of the discharge path is reduced to a low value compared to its normal value, said circuit comprising means including a transformer coupled between the cathode and anode of the magnetron for periodically applying a high voltage across the discharge path of the magnetron, a rectifier and a load impedance element connected across said transformer for developing a control voltage in response to the discharge path impedance of the magnetron said control voltage being at a relatively high or low voltage level when the discharge path impedance is at a normal or low value respectively, a time-constant network coupled across said load impedance element for integrating said control voltage to develop an output voltage corresponding in amplitude to the number of successive discharge path breakdowns, and relay means coupled to said means and to said time-constant network for disconnecting said means from the magnetron in response to said output voltage exceeding a predetermined amplitude corresponding to a predetermined number of successive discharge path breakdowns.

2. A protective circuit for a magnetron having a cathode and an anode, the magnetron being subject to sparking, whereby the resistance between the cathode and anode of the magnetron is reduced to a value small compared to its normal value, said circuit comprising a high voltage supply, a pulse-forming network, a transformer having a primary winding connected in series with said pulse-forming network across said high voltage supply, said transformer having a secondary winding connected between the cathode and anode of the magnetron, an electron discharge device connected across said high voltage supply, means coupled to said electron discharge device for periodically rendering said electron discharge device conducting to develop a voltage pulse across the secondary winding of said transformer and to render the magnetron conducting, means coupled to said high voltage supply for energizing said high voltage supply including a source of voltage and a relay connected in series with said high voltage supply, a rectifier and a load impedance element connected in series across said high voltage supply, said rectifier being poled to be rendered conducting in response to sparking of the magnetron, circuit means connected across said load impedance element and including a resistor-capacitor network responsive to the conduction of said rectifier to build up a control voltage thereacross, and means coupled between said resistor-capacitor network and said relay and responsive to said control voltage for deenergizing said relay to disconnect said source of voltage from said voltage supply in response to conduction of said rectifier for a predetermined period of time corresponding to a predetermined number of sparkings of the magnetron.

3. A protective circuit for a magnetron having a cathode and an anode, the magnetron being subject to sparking, whereby the resistance between the cathode and anode of the magnetron is reduced to a value small compared to its normal value, said circuit comprising a high voltage supply, a pulse-forming network, a transformer having a primary winding connected in series with said pulse-forming network across said high voltage supply, said transformer having a secondary winding connected between the cathode and anode of the magnetron, an electron discharge device connected across said high voltage supply, means coupled to said electron discharge device for periodically rendering said electron discharge device conducting to develop a voltage pulse across the secondary winding of said transformer and to render the magnetron conducting, means coupled to said high voltage supply for energizing said

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high voltage supply including a source of voltage and a relay, a first rectifier and a load impedance element connected in series across said high voltage supply, a second rectifier, a first resistor and a capacitor connected in series with said second rectifier across said load impedance element, a second resistor connected in parallel with said capacitor, the resistance of said first resistor being small compared to that of said second resistor, said rectifiers being poled to be rendered conducting upon sparking of the magnetron to build up a control voltage across said capacitor, and means coupled between said capacitor and said relay and responsive to said control voltage for deenergizing said relay to disconnect said source of voltage from said voltage supply in response to conduction of said second rectifier for a predetermined period of time corresponding to a predetermined number of sparkings of the magnetron.

4. A protective circuit for a magnetron having a cathode and an anode, the magnetron being subject to sparking, whereby the resistance between the cathode and anode of the magnetron is reduced to a value small compared to its normal value, said circuit comprising a high voltage supply, a pulse-forming network, a transformer having a primary winding connected in series with said pulse-forming network across said high voltage supply, said transformer having a secondary winding connected between the cathode and anode of the magnetron, an electron discharge device connected across said high voltage supply, means coupled to said electron discharge device for periodically rendering said electron discharge device conducting to develop a voltage pulse across the secondary winding of said transformer and to render the magnetron conducting, means coupled to said high voltage supply for energizing said high voltage supply, a first rectifier and a load impedance element connected in series across said high voltage supply, a second rectifier, a first resistor and a capacitor connected in series with said second rectifier across said load impedance element, a second resistor connected in parallel with said capacitor, the resistance of said first resistor being small compared to that of said second resistor, said rectifiers being poled to be rendered conducting upon sparking of the magnetron to build up a control voltage across said capacitor, and means coupled between said capacitor and said energizing means and responsive to said control voltage for disconnecting said voltage supply in response to conduction of said second rectifier for a predetermined period of time corresponding to a predetermined number of sparkings of the magnetron.

5. A protective circuit for a magnetron having a cathode and an anode, the magnetron being subject to sparking, whereby the resistance between the cathode and anode of the magnetron is reduced to a value small compared to its normal value, said circuit comprising a high voltage supply, a pulse-forming network, a transformer having a primary winding connected in series with said pulse-forming network across said high voltage supply, said transformer having a secondary winding connected between the cathode and anode of the magnetron, a first electron discharge device connected across said high voltage supply, means coupled to said first electron discharge device for periodically rendering said first electron discharge device conducting to develop a voltage pulse across the secondary winding of said transformer and to render the magnetron conducting, a rectifier and a load impedance element connected in series across said high voltage supply, said rectifier being poled to be rendered conducting in response to sparking of the magnetron, circuit means connected across said load impedance element and including a resistor-capacitor network responsive to the conduction of said rectifier to build up a control voltage thereacross, a second electron discharge device, a first relay connected in circuit with said second electron discharge device, means coupled to said first relay for normally energizing said first relay and said second electron discharge device, said second electron discharge device being coupled to said resistor-

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capacitor network for rendering said second electron discharge device nonconducting in response to said control voltage exceeding a predetermined amplitude corresponding to a predetermined number of successive sparkings of the magnetron, a second relay coupled to said first relay and controlled thereby, means coupled to said second relay for energizing said second relay, said second relay being deenergized in response to deenergization of said first relay, and circuit means for energizing said high voltage supply including a source of voltage and said second relay, whereby said high voltage supply is deenergized in response to said control voltage exceeding said predetermined amplitude.

6. The protective circuit defined in claim 2 wherein said electron discharge device is a thyatron.

7. The protective circuit defined in claim 2 wherein said resistor-capacitor network has a time constant that is long enough so that occasional sparking of the magnetron will not cause deenergization of said relay.

8. The protective circuit defined in claim 2 wherein said

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means responsive to said control voltage includes a further electron discharge device for controlling said relay.

9. The protective circuit defined in claim 2 wherein said resistor-capacitor network includes a capacitor, a first resistor connected in parallel to said capacitor, and a second resistor connected serially with said capacitor across said load impedance element.

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